Precision Agriculture in California: Developing Analytical Methods to Assess Underlying Cause and Effect of Within-Field Variability

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Introduction

The rising appreciation for the strong controls on yield exercised by short-range spatial variability of natural resources in agricultural fields led to the developing field of site-specific farming or precision agriculture. The variable application of fertilizer, seed varieties, pesticides and other management practices has shown great potential for creating more efficient and sustainable agroecosystems. This shift in focus of agriculture from uniform site management to site-specific management has led to a similar shift in data needs for farmers and researchers. Although accuracy and reproducibility are still essential, more attention has been paid to fast, inexpensive, if possible on-the-go analyses of soil and crop parameters. Some of the most popular methods of analysis have been data sources that can be used to predict a variety of soil/crop parameters simultaneously, such as remote-sensing imagery and electromagnetic measurements. Infrared (IR) spectrometry in the near- and mid-infrared range shows considerable promise for making fast, inexpensive and accurate predictions within a precision agriculture context. Within agriculture, IR spectrometry is already routinely used in predicting protein content, moisture levels and fat content of food products and forage crops. More recently, there has been interest in using IR spectrometry for predicting soil properties, especially C and N content and moisture.

The mid-infrared (MIR) spectrum has been often used for qualitative analyses of organic substances. Due to relatively simple sample preparation procedures, diffuse reflectance

Fourier transformed (DRIFT-MIR) approaches have been especially popular. There are a number of studies on DRIFT-MIR spectrometry for characterizing organic matter decomposition. To our knowledge, there are no reported studies linking DRIFT-MIR spectrometry of soils to crop properties in the subsequent growing season.

Objectives

1) To compare the performance of NIR and DRIFT-MIR spectrometry of soils for predicting soil and crop properties in rice systems,
2) Assess possibilities for NIR and/or DRIFT-MIR spectrometry under specific precision agriculture conditions.

Description

Two transects of 400 m each in a rice field, located in the Butte County, were left unfertilized, and 100 sample locations were established. Soil samples were taken in spring, and crop and weed samples at harvest. IR spectra were linked to total soil C and N, mineralizable N, P Olsen, effective cation exchange capacity (eCEC) and exchangeable cations (Ca, Mg, Na and K), as well as yield, N uptake, biomass and weed biomass using partial least squares regression (PLSr). The PLSr models were calibrated using 50 random observations, and validated using the remaining 50 observations.

Results and Conclusions

For soil, predictions for eCEC, Ca and Mg were the most accurate, with r^2 values of 0.83, 0.80 and 0.90 for NIR and 0.56, 0.60 and 0.61 for DRIFT-MIR. Correlations for P Olsen were 0.71 and 0.55, and for mineralizable N 0.46 and 0.21, respectively. No significant correlations were found for total soil C or N. For crop parameters, only weed pressure (r^2 of 0.55 and 0.44) and straw biomass (0.30 and 0.34) yielded significant correlations. The correlation with weed pressure was an indirect effect due to better competition by weeds compared to rice under low soil fertility levels. For most parameters, standard errors of prediction were lower than reported in the literature. This indicates that the small range of variability within a field might be the limiting factor in predicting these parameters. It also illustrates the limited use of correlation coefficients in PLSr model validations. We concluded that NIR spectrometry shows promise for site-specific Management practices, although its predictive power for parameters may vary from site to site. Moreover, predictive models remain unique for specific agroecosystems, and therefore have to be calibrated for every area. The fast and accurate predictions for Ca and Mg concentrations in the soil could be especially important in diagnosing and combating grass tetany, which strongly depends upon Ca and Mg concentrations in the soil.

Implications for use in site-specific management

It is clear from this study that NIR performs better in terms of predictive power than DRIFT-MIR. The r^2 values of 0.83, 0.82 and 0.71 for eCEC, Mg and P are much higher than the corresponding numbers of 0.56, 0.61 and 0.55 for DRIFT-MIR. In terms of prediction error, this corresponds to an improvement of approximately 30 % for NIR. Combined with the more complicated sample preparation and the more expensive equipment for DRIFT-MIR, and the possibilities for installing NIR sensors on farm equipment (Ehsani et al., 1999), NIR spectrometry is preferred.

As noted above, the low prediction accuracy for most crop parameters and soil total C and N might be due to the relatively small variation in these parameters within our study area. Since our prediction error for total soil N and N uptake was similar or lower than those reported, differences in these parameters in our fields may simply be below the detection limits for IR spectrometry. This could have important consequences for its use in site-specific management (SSM).

However, the significant results for Ca, Mg, eCEC and P Olsen certainly warrant the use of IR spectrometry in SSM. In this respect, it is important to stress that predictive models built with PLSr are unique to the area on which they were calibrated. Texture, mineralogical composition, organic matter content and other variables all strongly influence the reflectance spectra, and will therefore have an effect on the optimal model parameters. For example, Ben-Dor and Banin (1995) reported 2333, 2097 and 1431 nm as the most important wavelengths for

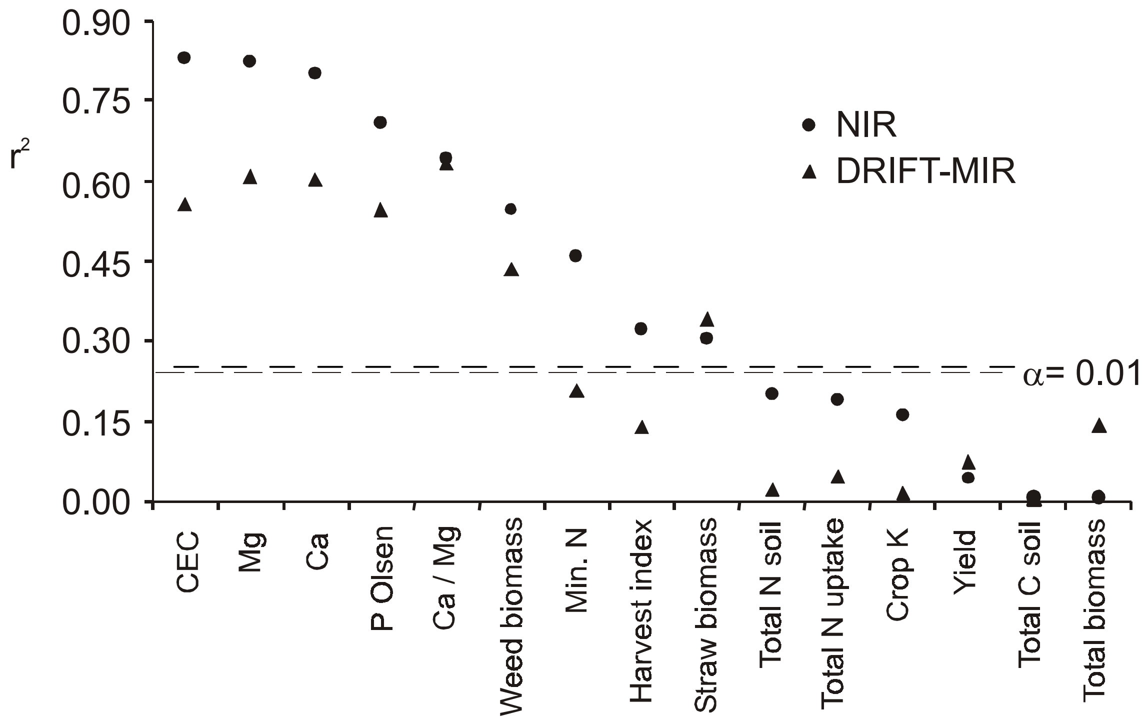

Fig. 1. Regression coefficients for the DRIFT-MIR spectrum in the PLS models, for soil parameters with a significant correlation with the spectra.

predicting CEC. In our case, the most important wavelengths are around 900, 2420 and 2290 nm. For effective use in precision agriculture, PLSr models need to be calibrated for the area over which they will be used. However, it is expected that, once calibrated, these models can be used for predictions over different growing seasons.

Conclusions

Both NIR and DRIFT-MIR spectrometry, combined with PLSr modeling, could simultaneously predict a range of soil and crop properties under conditions typical for precision agriculture (i.e. relatively minor variations within a field). Compared to other studies, we had low correlation coefficients but very good SEP's. This indicates that variation within a field might be too small to be detected precisely by IR spectrometry for some properties. It also illustrates that correlation coefficients are of very limited value in describing the accuracy of such predictive models. In our study area, NIR performed better, with r^2 values higher than 0.90 for eCEC and basic cations higher than 0.80. NIR spectrometry, especially implemented as a sensor in farm equipment for on-the-go analysis, offers considerable perspective in precision agriculture for instantaneous, simultaneous and inexpensive prediction of a variety of soil and crop parameters. PLSr models need to be built using a calibration set specific to the research area in order to yield reliable predictions.